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## Quantification of the effect of Body Mass Index on Cricothyroid Membrane Depth

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## Emergency Medicine Journal

### **Quantification of the effect of Body Mass Index on Cricothyroid Membrane Depth: a cross-sectional analysis of clinical CT images**

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**Quantification of the effect of Body Mass Index on Cricothyroid Membrane Depth: a cross-sectional analysis of clinical CT images**

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## Abstract

**Objectives:** The recommended front of neck access (FONA) procedure in can't intubate, can't oxygenate (CICO) scenarios relies on palpation of the cricothyroid membrane (CTM), or dissection of the neck down to the larynx if CTM is impalpable. CTM palpation is particularly challenging in obese patients, most likely due to an increased distance between the skin and the CTM (CTM depth). The aims of this study were to measure the CTM depth in a representative clinical sample, and to quantify the relationship between body mass index (BMI) and CTM depth.

**Methods:** This is a retrospective analysis of 355 clinical CT scans performed at a teaching hospital over an 8-month period. CTM depth was measured by 2 radiologists, and mean CTM depth calculated. Age, gender, height, and weight were recorded, and BMI calculated. Linear relationships between patient characteristics and CTM depth were assessed in order to derive a predictive equation for calculating CTM depth. The variables included for this model were those with a strong association with CTM depth, i.e. a p-value of 0.10 or less.

**Results:** Mean CTM depth was 8.12mm (IQR 6.36, 11.70). There was no association between CTM depth and sex ( $\beta$  -0.33 (95% CI -1.33 to 0.68)  $p=0.53$ ), height (cm) ( $\beta$  0.01 (95% CI -0.05 to 0.06)  $p=0.79$ ) or age (years) ( $\beta$  -0.01 (95% CI 0.10 to 0.15)  $p=0.62$ ). Increasing weight (kg) ( $\beta$  0.12 (95% CI 0.10 to 0.15)  $p<0.001$ ) and BMI ( $\text{kg}/\text{m}^3$ ) ( $\beta$  0.52 (95% CI 0.44 to 0.60)  $p<0.001$ ) were strongly associated with CTM depth. Predicted CTM depth increased from 6.4mm (95% CI 4.9 to 8.1) at a BMI of 20  $\text{kg}/\text{m}^2$  to 16.8 (95% CI 13.7 to 20.1) at BMI 40  $\text{kg}/\text{m}^2$ .

**Conclusion:** CTM depth was strongly associated with BMI in a retrospective analysis of patients having clinical CT scans.

### What This Paper Adds

**Section 1- What is already known on this subject:** Other than some exploratory work in small selective samples, CTM depth has not yet been accurately quantified in representative cadaveric or clinical cohorts. Our primary aim was to quantify CTM depth in a large, clinical sample.

**Section 2- What this study adds:** In this study measuring the CTM from CT scans of 355 trauma patients, we quantified with some accuracy the range of CTM depths encountered in clinical practice. We have also reported BMI-specific values that may have utility in planning for unanticipated airway problems.

## Introduction

Failure to intubate the trachea after induction of general anaesthesia (failed intubation) is uncommon, occurring in approximately 1 in 2,000 cases.<sup>1,2</sup> In comparison, the rate of difficult intubation in emergency department (ED) may be as high as 8-12%.<sup>3-6</sup> The situation where failed intubation is followed by an inability to provide oxygenation (can't intubate, can't oxygenate (CICO)) is less frequent but potentially catastrophic, resulting in a quarter of all anaesthesia-related deaths.<sup>7,8</sup> The higher rates of difficult intubation may mean this is a more likely scenario in the emergency management of patients in ED. Also, interestingly, a study looking at pre-hospital airway management found that non-anaesthetists are twice as likely to perform a rescue airway intervention.<sup>9</sup>

Front of neck access (FONA) is the final attempt to oxygenate a patient in these circumstances. The Difficult Airway Society (DAS), in their updated 2015 national guidelines, recommended a scalpel technique for FONA, on the basis that this is the most rapid and reliable method under the circumstances.<sup>10</sup> The recommendation differs according to whether or not the cricothyroid membrane (CTM) is palpable: either a single transverse stab incision through the CTM using a number 10 or 20 scalpel (palpable CTM), or an 8-10 cm vertical incision followed by blunt dissection to locate the larynx (impalpable CTM).

CTM palpation is particularly challenging in obese patients,<sup>11,12</sup> with CTM identified reliably in only 39% of obese compared with 71% in the non-obese necks.<sup>7</sup> The distance between skin and CTM (CTM depth) is likely to be important<sup>13</sup> potentially affecting the success of CTM palpation and scalpel-based FONA techniques.<sup>14</sup> Other than some exploratory work in small, selective samples, CTM depth has not yet been accurately quantified in representative cadaveric<sup>15-17</sup> or clinical cohorts.<sup>13,14</sup>

Our primary aim was to quantify CTM depth in a large, clinical sample. Our secondary aim was to establish the relationship between body mass index (BMI) and CTM depth, by using a predictive equation, to provide guidance to clinicians considering FONA in obese patients.

Confidential: For Review Only



## Materials and Methods

The use of patient data for the study was approved by the Caldicott Guardian for NHS Lothian. The study was discussed with a representative from Academic and Clinical Central Office for Research and Development (ACCORD), who considered the study to be an evaluation of clinical practice and not research. Requirement for research ethics committee approval was therefore waived. The study is reported according to the Strengthening the Reporting of Observational Research in Epidemiology (STROBE) statement.<sup>18</sup>

We conducted a retrospective cross-sectional study. A TRAK (NHS Lothian Patient Management System) search for all CT cervical spine requests from the emergency department at the adult teaching hospital between 1<sup>st</sup> of January 2016 to 24<sup>th</sup> of August 2016 were included. Any scans with artefact precluding accurate measurement (movement, intubated patients, inadequate position/coverage, skin folds, beam hardening, extreme neck position/neck deformity, forensic scan.) were excluded. Duplicate scans (subsequent scans for the same patient) were not analysed. Where available, the following clinical variables were identified from the electronic patient record: indication for CT, age, sex, height, and weight.

We had no data on CTM depth prior to starting the analysis so a power calculation was not possible. We chose to include consecutive cases spanning a period of 8 months and sample size was determined by the inclusion period.

## Statistical Analysis

All statistical analyses were conducted in R.<sup>19</sup> Two radiologists (TB, DP) independently measured the shortest CTM depth in each image by identifying the CTM and measuring the distance from the deep surface of the CTM to the skin. Multiplanar reformats of the scans were performed to check the measurements representing the shortest distance. The caliper tool in the Carestream Vue Picture Archiving and Communication System (PACS) was used to make the measurements. The mean of these 2 measurements was used for analysis. (see figure 1)

Patient characteristics were reported as mean (SD) if normally distributed or median (IQR). CTM depth was reported as median (IQR) and mean (SD). The association between each patient characteristic (age, sex, height, weight and BMI) and CTM depth were tested by entering them individually into a univariable linear regression model. Patient characteristics that were found to have a strong association with CTM depth (defined by a p-value of 0.10 or less) were considered for inclusion in a multivariable linear regression model. Due to the co-linearity of BMI, weight, and height, BMI was not included in models containing the other 2 variables. To illustrate the potential utility of the derived model, we planned to use the beta-efficients of included variables in a predictive equation for CTM depth using the formula:  $CTM\ depth = a + b_1x_1 + b_2x_2 + \dots + b_nx_n$ , where  $a$  = y intercept and  $b_n$  represents the beta coefficient for each included variable. Cinical impact was assessed by calculating predicted depth for patients falling within WHO BMI sub-categories.<sup>20</sup>

#### ***Patient and Public Involvement***

No patient involved.

## Results

Three hundred and ninety-four CT scans were identified during the 8-month period; of 39 scans were excluded: 35 due to suboptimal images, and 4 were duplicate scans. Following exclusions, 355 scans (90%) were included in the analysis. Height was available for 185 (52%) and weight was available for 193 (54%) of included patients. (Table 1.)

In the whole sample ( $n=355$ ), CTM depth was 8.1mm (IQR 6.4, 11.7). In univariate analyses there was no difference in CTM depth between male with female patients and no association between CTM depth and patient height or age. Increasing weight and BMI were strongly associated with CTM depth ( $p<0.001$ ); see also figure 2). Except for height and weight, no other variables met the  $p$  value threshold in a multivariable model, and since BMI and weight linearly related, multivariable models were not constructed. Predicted CTM depths with confidence intervals for different BMI thresholds have been calculated using the derived regression equation and are reported in table 3 to illustrate the clinical impact of higher BMI on CTM depth. Predicted CTM depth increased from 6.4mm (95% CI 4.9 to 8.1) at a BMI of 20 kg/m<sup>2</sup> to 16.8 (95% CI 13.7 to 20.1) at BMI 40 kg/m<sup>2</sup>.

To assess whether there were differences between patients with missing values for BMI, we grouped patients according to whether or not BMI was available and examined available characteristics between groups and found no obvious differences, as shown in the Supplemental Table.

## Discussion

In a large sample of patients undergoing CT scans as part of routine care, we evaluated CTM depth and observed a mean CTM depth of 8.1mm with significant inter-individual variation. We observed strong linear relationships between weight, BMI and CTM depth, with obese patients having up to 3-fold increases in CTM depth compared to non-obese individuals. While this is not the first study to suggest that BMI and CTM depth might be related, the larger size of our study allowed us to quantify with some accuracy the range of CTM depths encountered in clinical practice.

The 2011 National Audit Project 4 (NAP4) – a prospective study of all major airway events in the United Kingdom – reported the incidence of major airway events to be 1 in 22,000 anaesthetics. Of the 133 anaesthesia-related cases reported, 58 cases (43%) required FONA, compared to 67% (10 of 15) in ED. All 3 patients with needle cricothyroidotomy in ED required conversion to a surgical technique. Two of the 15 patients died and 1 suffered persistent brain damage.<sup>21,22</sup>

In response to the high failure rates of needle cricothyroidotomy amongst all practitioners, DAS refined their guidance to recommend one of 2 scalpel techniques described above, thus removing the choice between a scalpel and needle in the event of an airway emergency.<sup>9</sup> The change overcame the problems associated with cannula cricothyroidotomy, mainly the lack of appropriate airway equipment and the necessary attachments for prompt re-oxygenation. However, the recommended approach now relies on the palpation of the trachea through the skin, or the ability to access the trachea by directly cutting down onto it. The success of both techniques is likely to be dependent on the amount of soft tissue between the skin and the cricothyroid membrane – the CTM depth.

Although most physicians will anticipate that a higher BMI would increase the risk of airway management, including failed FONA, our study provides an indication as to when the cut down technique may be more appropriate in these patients. It is also possible that bedside ultrasound could be used so that those with a high BMI could have an accurate CTM depth measured at bedside prior to FONA, hence both identifying the CTM and assisting the physician in deciding which technique may be best to use.

Previous investigators have recognised the potential importance of increased CTM depth as a mechanism for FONA failure during anaesthesia in late pregnancy.<sup>13,14</sup> In one of these, Gadd et al used ultrasound scan (USS) to compare 15 non-obese (BMI <25kg/m<sup>2</sup>) with 15 super-obese (BMI >45kg/m<sup>2</sup>) parturient patients and found a mean difference of over 7mm between the groups.<sup>13</sup> Whilst this study was not large enough to quantify the relationship between BMI and CTM depth across the whole range of BMIs, and was limited to a pregnant population, the study demonstrated eloquently the reliable use of USS as a tool for measuring this parameter.

Several limitations are worthy of comment. First, our sample was retrospective and selected from a clinical dataset of patients who had an indication for a CT scan. As a result, patients may not perfectly represent our target population. Second, although considerable efforts were made to obtain data on BMI, this was only available in half of our patients. While we found no difference in patient characteristics between those included and excluded from analysis, we cannot entirely rule out a non-random pattern of missingness that may have biased our regression analysis. Third, as this was a retrospective study, measurements were taken in a neutral neck position, rather than the extended position advocated for front-of-neck access and this may mean that CTM depth in a “real life” setting may differ marginally

from our estimates. Finally, the predictive score derived should not be used clinically as it has not been validated in a sample other than that from which it was derived. Further validation is required.

In conclusion, average CTM depth in this sample of trauma patients requiring cervical CT scans was 8.1mm. Increased BMI was strongly associated with CTM depth. Future data are required to establish the CTM depth threshold that renders the CTM impalpable, and FONA hazardous, as well as the role of ultrasound in measuring the CTM depth.

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**Contributorship**

All authors have contributed to the production of this work.

SG - Idea, methods, patient selection, extraction of patient data, writing of manuscript - including statistics, tables and figures. Revision and review of manuscript.

TM & DP - Measurement of CTM depth on CT scans. Review of final manuscript.

CT - Ideas, help with methods and patient selection, review of final manuscript.

DG - Statistics, manuscript - including statistics, tables and figures. Revisions and review of manuscript.

**Competing Interests**

No external funding and no competing interests declared

**Data Sharing/Data Availability**

All data relevant to the study are included in the article or uploaded as supplementary information

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Tables

Table 1: Patient Characteristics for 355 included CT scans

Age (years +/- SD)	56 (23)
Male Sex ( N/%)	213 (60%) )
Height (cm) (N=185)	169 (11)
Weight (kg) (N=193)	73 (20)
BMI <sup>§</sup> (kg/m <sup>2</sup> ) (N=175)	25 (6)
WHO BMI Category (n%)	
Underweight	9 (5)
Normal	83 (47)
Pre-obese	54 (31)
Obesity I	19 (11)
Obesity II	7 (4)
Obesity III	3 (2)
Indication (n/%)	
Assault	18 (5)
Atraumatic head/neck pain	5 (1)
Attempted Hanging	4 (1)
Collapse	16 (5)
Collapse/Seizure	7 (2)
Fall	184 (52)
Found Unresponsive	11 (3)
Head Injury	8 (2)
Hit by Heavy Object	4 (1)
Preoperative CT	1 (0.3)
Road traffic collision	90 (25)
Sporting Injury	5 (1)
Staging CT	1 (0.3)
Unclear	1 (0.3)

Data presented as mean (SD); or n (%)<sup>§</sup>BMI: Body mass index

Table 2: Univariate linear relationship between patient characteristics and cricothyroid membrane depth. \*Cricothyroid membrane depth measured in mm. \*Female as baseline.

Characteristic	n	Intercept*	Coefficient	95% Confidence Interval		P
				2.5%	97.5%	
Sex <sup>+</sup>	359	9.69	-0.33	-1.33	0.68	0.53
Age (years)	354	9.78	-0.01	-0.03	0.02	0.62
Height (cm)	187	7.96	0.01	-0.05	0.06	0.84
Weight (kg)	195	0.39	0.12	0.09	0.14	<0.001
BMI (kg/m <sup>2</sup> )	177	-3.96	0.52	0.44	0.60	<0.001

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Table 3: Predicted depths\* for different BMI thresholds based on the derived regression equation.

BMI (kg/m <sup>2</sup> )	Predicted depth (95% CI) mm
20	6.4 (4.9 to 8.1)
25	9.0 (7.1 to 11.1)
30	11.6 (9.23to 14.1)
35	14.2 (11.5 to 17.1)
40	16.8 (13.7 to 20.1)

\*Calculation for predicted depth: -3.96 + (BMI\*0.52)

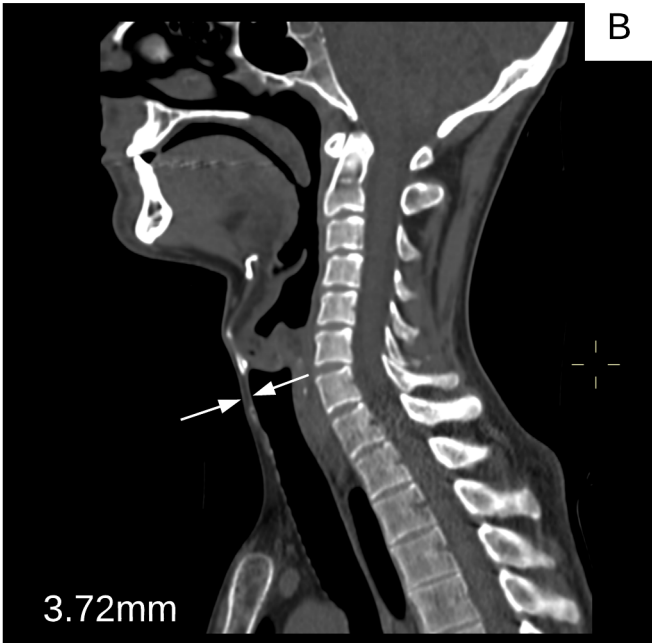
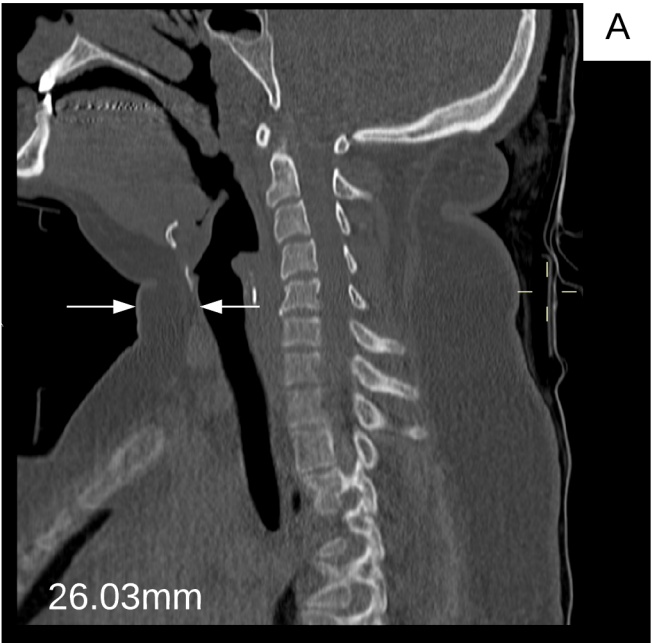
**Figure Captions**

Figure 1 – Sagittal CT images of cricothyroid membrane (CTM) depth in patients with large (A) and small (B) necks.

Figure 2 – Scatter plot showing relationship between body mass index and cricothyroid membrane depth.

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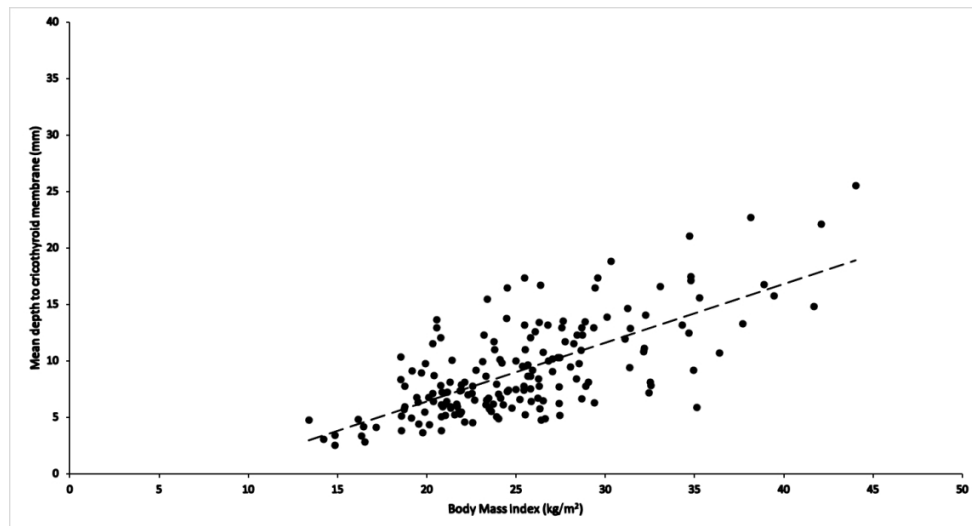


Figure 2 – Scatter plot showing relationship between body mass index and cricothyroid membrane depth.



Supplemental Table: Comparison of patient characteristics in patients with / without complete body mass index (BMI) data. Data presented as mean (SD); n (%) or median (Q1, Q3). \*CTM: Cricothyroid membrane. <sup>§</sup>BMI: Body mass index

	BMI <sup>§</sup> missing	BMI available
n	180	175
Male (%)	109 (6)	104 (59)
Age	50 (20)	62 (23)
Skin to CTM* (mm)	9.76 (5.20)	9.17 (4.19)
Indication		
Assault	9 (5)	9 (5)
Atraumatic head/neck pain	3 (2)	2 (1)
Attempted Hanging	4 (2)	0 (0)
Collapse	6 (3)	10 (6)
Collapse/Seizure	2 (1)	5 (3)
Fall	82 (46)	102 (58)
Found Unresponsive	6 (3)	5 (3)
Head Injury	5 (3)	3 (2)
Hit by Heavy Object	3 (2)	1 (0.6)
Preoperative CT	0 (0)	1 (0.6)
Road traffic collision	55 (31)	35 (20)
Sporting Injury	4 (2)	1 (0.6)
Staging CT	0 (0)	1 (0.6)
Unclear	1 (0.6)	0 (0)